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RESEARCH IN THIN FILM MEMORIES

by

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13. ABSTRACT

The Research Institute for the Communication-Technological Industry investigates the technology and structure of thin magnetic-layer memories for the past five years. Data on the vapor-deposited plane memories and wire memories were presented. Electron micrographs were presented of a 80/20 Ni/Fe layer (15,000 X magnification), a 60/40 Ni/Fe layer (15,000), and a pure Fe layer (15,000). The instrument devised for establishing the hysteresis characteristics and some hysteresis diagrams for a 81/19 Ni/Fe layer were shown. The wire memories were found to have a number of advantages over the plane memories, but they are more heat-sensitive.

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RESEARCH IN THIN FILM MEMORIES

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The performance of any computer is primarily determined by the capacity and access time of the computer memory. Therefore, during the past 10-15 years the primary objective in computer design was to increase the capacity and the access speed of the memory unit. It may be noted that development was nearly exponential with respect to calendar time, and access speed, as well as memory capacity, were doubled approximately once every three years.

In recent years, the most widely used memory unit was the ferrite core memory matrix made of magnetic ferrite rings. Development of this type of memory was largely pursued along the lines of reducing core size, as this would increase access speed greatly. Development was also achieved through the automatic selection of the rings, as well as by the development of automatic machinery for the assembly of the matrix.

Papers published in the past few years, however, show that the monopoly of the ferrite memories has now been broken with the

development of new memory types. Most important among these new memory types are the memories formed of thin magnetic films. Among the thin film memories, two subtypes deserve particular note, one being the type based on a thin film plane matrix, the second is the cable type that is sometimes referred to as a plated wire memory.

In our institute, we have for the past five years occupied ourselves with research in the technology and construction of thin film memories.

Thin Film Deposits Manufactured Through Vapor Deposition Methods

The primary advantage of such storage devices are the substantially higher access speeds, which are the result of the need to magnetize only a very limited mass of the thin film. Magnetization time is on the order of 10 to 30 ns. Another advantage is the relatively low demands made on the magnetic elements. The disadvantage of thin film memories is the relatively low signal voltage (approximately 1 mV). The primary reason for the low signal voltage is the fact that the magnetic loop is in part closed only through air.

We produced thin Permalloy magnetic layers through vacuum deposition methods, with a composition of approximately 81% Ni and 19% Fe on glass and metal plates. Considering the fact the vapor pressures of the two metals were different, one had to apply a vapor deposition method that assured with reasonable certainty that the desired Fe-Ni composition was met. This problem could be solved by flash type vapor deposition methods. In this procedure the temperature of the vapor source is considerably higher than the boiling point of the metals.

The vapor deposition in this case is instantaneous, and therefore it is possible to make the alloy composition of the lower layers identical with the composition of the material desired on top.

The supply system of the vapor source consists of a vibrator actuated container and the associated trough. The powdered metal mixture, or as the case may be, alloy shavings, drop onto the heated elements and are instantaneously vaporized.

The anisotropic characteristics of thin magnetic films are well known. There is one direction, in which magnetic flux will magnetize the thin film with ease; in the direction perpendicular to that, the thin film is hard to magnetize. We may intensify the anisotropic characteristics of thin films by performing the vapor deposition in the presence of a magnetic field. This may be done through the use of a Helmholtz coil. With this coil, a nearly homogeneous magnetic field may be produced with a field strength of approximately 300 Oe volts. This level was actually reached in the course of our experiments, which produced a film thickness of approximately 1000 Å.

Our first task was to investigate the chemical and physical characteristics of thin films.

The composition of thin films is studied by x-ray refraction methods. These methods are based on the fact that the intense primary x-ray radiation emitted from an x-ray tube anode made of material with a high atomic number (such as tungsten) causes the surface of the sample to emit secondary x-rays with characteristics that are unique to the material of teh sample. The radiation is analyzed by being passed through a crystal (such as LiF) which permits rotation through 0 to 120° and resolution into component parts. The percentage Ni-Fe composition of the sample may be determined from the intensity of the secondary radiation, which may be measured with a scintillation counter.

The morphology of the films was studied under an electron microscope. Changes in the morphology were again checked after a five-week storage. The investigations were extended to storage in a moist environment, which permitted the study of the effects of

corrosion on the film. These investigation were corducted for films with various Ni-Fe compositions. Figures 1 and 2 show the pictures taken with electron microscopes during these studies. The results of the investigations showed that the greatest corrosion resistance was found in films with a composition of 80% Ni and 20% Fe. We found that corrosion increased rapidly with Fe content. The corrosion in pure Fe is shown on Figure 3.

Figure 1. Electron microscopic picture of a magnetic thin film consisting of 80% Ni and 20% Fe (enlarged 15000 X).

Figure 2. Electron microscopic picture of a magnetic thin film consisting of 60% Ni and 40% Fe (enlarged 15000 X).

Figure 3. Electron microscopic picture of a magnetic thin film of pure iron (enlarged 15000 X).

The thickness of the layer was measured by interferometric methods. The study of the magnetostatic characteristics of the layer were then undertaken. For this purpose, we set up equipment to establish the hysteresis curve of the films. The equipment presented the hysteresis curve of the film being tested on the screen of an oscilloscope. The operational description of the equipment is as follows:

Inside a larger coil, we generated a homogeneous magnetic field with a frequency of 1 KHz. The strength of the magnetic field inside the coil is given by:

$$H = k_1 I_0 \sin \omega t$$

In addition to this first coil, we also used a secondary sensing coil, inside of which we placed the thin film specimen to be investigated. In this coil, under the influence of flux Φ, which is proportional to induction B, the voltage U rises. The magnitude of the voltage is given by

$$U = k_2 \frac{d\Phi}{dt}$$

If we integrate the voltage, then we get the magnetic flux, which is proportional to the induction:

$$\Phi = k_3 \int U dt.$$

If, onto the horizontal input of the oscilloscope, we connect current I, which is proportional to magnetic field H, and if onto the vertical input we connect voltage U which is proportional to the values of Φ and B, then the screen will show the hysteresis loop of the specimen.

There is a special test bench associated with this test setup. The sensing coil is located within this test bench. Provision is made on the bench to rotate the test specimen to various angles with respect to the sensing coil. The anisotropic characteristics of the thin film can thereby also be studied. A picture of the test bench is given in Figure 4. The hysteresis loop for a film composed of 81% Ni and 19% Fe is shown in Figure 5, complete with the directions in which the thin film is easy and difficult to magnetize. The easy and difficult directions form an angle of nearly 90° with respect to each other. Deviations from 90° are shown by the protractor on the test bench. After calibrating the equipment, it was possible to

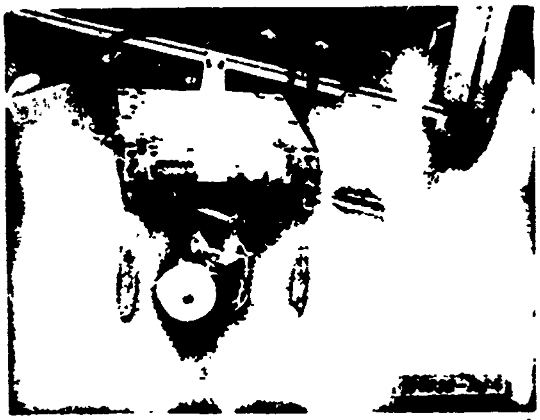

Figure 4. Test bench for hysteresis tests.

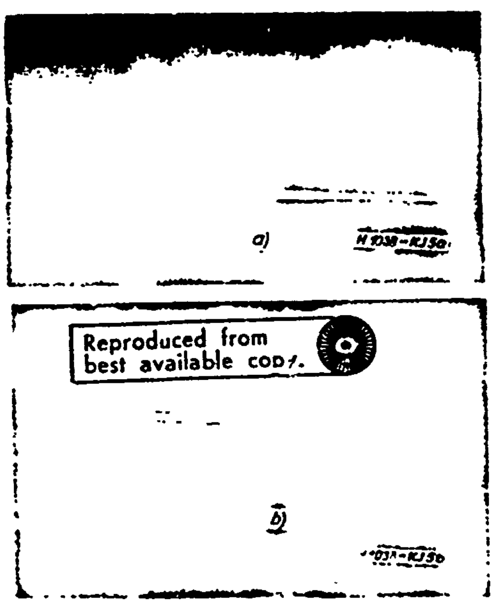

Figure 5. Hysteresis characteristics of a magnetic thin film consisting of 81% Ni and 19% Fe, in (a) the easy to magnetize direction; (b) the difficult to magnetize direction.

determine the magnetic parameters of the film, which are shown in Table 1.

The random scatter encountered in the characteristics of the film made by vapor deposition tests was substantially reduced. Data from repeated depositions showed that reproducible results could be achieved with vapor deposition techniques. In the course of the experiments we ordered the preparation of sample storage units. These sample storage units consisted of a three-word, four-bit matrix. The word line ran immediately above, and in contact with the magnetic layer. These leads were made of 30 μm thick copper foil through photolithographic methods. The digit line was prepared on a printed circuit board, also made by photolithographic methods, and crossed the word leads over the bit points. Figure 6 shows the configuration of the sample storage units.

Plated Wire Memories

During the year 1968, we started the first experiments to develop wire memories made with electrolytic deposition methods. Plated wire memories have become very widespread during the past

TABLE 1. MAGNETIC PARAMETERS OF A THIN FILM LAYER PRODUCED BY VAPOR DEPOSITION METHODS.

Coercive force in the easy direction H_{ck} O_c	Anistropy H_{ck}'H_{cn}	Induction needed to saturate B_s (Gauss)	Coercive force in the difficult direction H_{cn} O_c	* H_c/H_s	Deviation from 90°
4-1.5	2.0-2.25	7500-8000	2.0	0.9-0.95	5°

H_{ck} - coercive force in the easy direction.

H_{cn} - coercive force in the difficult direction.

H_k - strength of the anisotropic field, that is necessary to flip film into another magnetic state.

K_s - induction necessary for saturation in Gauss

H_s - Field strength corresponding to saturation.

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*Illegible in foreign text.

three years. In these memories, the thin film is deposited by electrolytic methods on a hard metal alloy wire (usually a berryllium-bronze alloy). Figure 7 shows the construction of such a plated wire memory unit. The digit signal is conducted through the line, which simplifies the construction of the memory unit considerably. The current going through the digit line establishes a closed magnetic loop in the magnetic film. Therefore, the signal strength from such a memory unit is greater than the signal strength derived from a simple planar thin film memory, by almost an order of magnitude. Another advantage of this type of memory is that its production is continuous, whereas that of the planar type is by units.

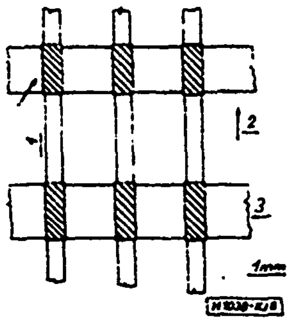

Figure 6. Layout of a planar thin film memory showing the digit and word lines: 1 - word line; 2 - easy direction; 3 - digit line.

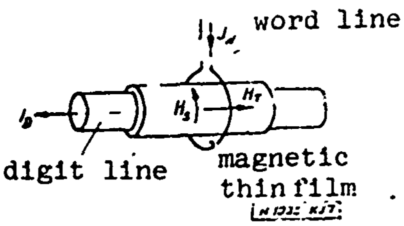

Figure 7. Diagram of one storage unit of a plated wire memory.

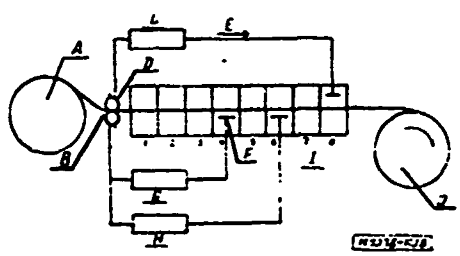

Figure 8. Schematic diagram of continuously-operating wire plating equipment. A - spool; B - cathode; C - power supply; D - ground; E - premagnetizing current; F - Cu anode; G - power supply; H - power supply; I - Permalloy anode; J - powered spool; 1 - trichlorate; 2 - ethyl alcohol; 3 - distilled water; 4 - copper plating; 5 - distilled water; 6 - Permalloy plating; 7 - distilled water; 8 - mercury contact.

The equipment for continuous production of cable memories is shown in Figure 8. In the first bath, the berrylium-bronze cable is degreased, the second bath is an alcohol bath, and the third bath cleans the cable in distilled water. Then the cable passes through the first plating bath, which plates it with copper in order to decrease the surface roughness of the cable. The smoothness of the cable surface is very important from the standpoint of the physical characteristics of the thin film layer. A rough surface on the cable can also result in local deterioration of the magnetic characteristics of the thin film.

Following the copper plating, there is another rinsing bath, then there is a second plating bath. This is the most difficult part of the process. It is in this bath that the thin film layer is formed on the cable. The bath

consists of Ni and Fe salts, as well as surface conditioning materials. The composition of the electrolyte was designed to ensure that the proportion of Ni ions to Fe ions in the deposited layer is in the ratio of 81 to 19. Provision must be made to maintain the chemical composition as well as the temperature of the bath stable. The anisotropic characteristics of the cable are assured through the magnetic field of a current conducted through the cable. This also determines the easy direction of magnetization. After this plating bath, there is another rinsing bath.

The more important magnetic parameters of the thin film produced by the above methods are shown in Table 2.

TABLE 2. CHARACTERISTICS OF MAGNETIC FILMS USED ON CABLE STORAGE DEVICES.

Coercive force in the easy direction H_{ck} O_c	Anistropy H_{ck}'H_{cn}	Induction needed to saturate B_s (Gauss)	Coercive force in the difficult direction H_{cn} O_c	* H_c/H_s	Deviation from 90°
3.5-4.5	1.1-0.85	16000-18000	3.2-5.2	0.8-0.85	5°

*Illegible in foreign text.

Storage plates may be made using the thin filmed cables. In one approach, the plated-cable was mounted on a plastic plate, and then soldered to the prefabricated contact points on the plate. The digit line is the cable itself, while the word lines are woven normally onto the digit line. This is shown in Figure 9. The figure shows the layout of a four-word, nine-bit storage device. In the second approach, the plated cables are separated by a plastic plate. Here too, the digit line is the berrylium-bronze plated cable. The word lines are strip conductors prepared of copper foil covered

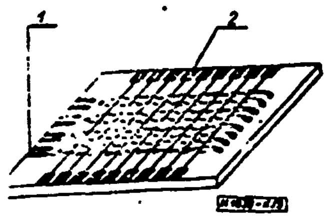

Figure 9. General arrangement of plated wire memory: 1 - word line; 2 - digit line.

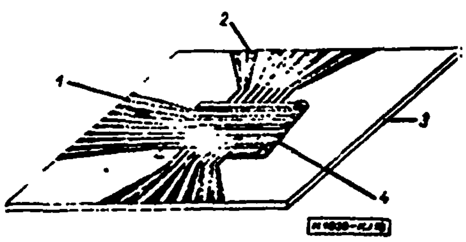

Figure 10. General arrangement of a strip line memory: 1 - word line; 2 - digit line; 3 - base plate; 4 - Melinex foil.

Figure 11. Photograph of complete four-word, nine-bit memories using plated cables.

plastic laminates with photolithographic etchings. These strip conductors enclose the digit line as shown in Figure 10. This arrangement is referred to as strip line construction. Photographs of complete storage devices are shown in Figure 11.

We have also prepared equipment to investigate the most important dynamic parameters of plated cable memories. Of these dynamic characteristics, the most important is the cycle time that is indicative of access speed, and the magnitude of the output signals. Table 3 shows these characteristics for plated wire memories.

On the basis of these investigations, it may be concluded that plated wire memories offer advantages that would seem to assure the rapid growth of their application. These advantages may be summarized as follows:

1. The closed magnetic loops make possible higher signal voltages than those of planar film memories.

TABLE 3. OPERATING CHARACTERISTICS OF PLATED WIRE MEMORIES.

Signal voltage mV	Flip-over time (2x) ns
2.3-4.8	120-180

2. The construction is simpler because the wire on which the film had been deposited also serves as the digit line.

3. Because the film thicknesses are selected to be between 2000 to 5000 Å, which is thicker than the layers used in plane thin film memories. As the amount of magnetic energy storing the information is proportional to the thickness of the film, the thicker film seems to make further increases in output signal voltage possible.

4. Due to the fact that the continuous production method is simpler, the expected unit cost is less than that of plane memories.

As the sole disadvantage, one may mention the sensitivity to temperature variations, as the line transferring the signal is in contact with the storage layer, and the heat generated by current within that line may influence the magnetic parameters of the film. The extent of these effects will be determined by the reliability studies that are presently being conducted.

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